Structure 2.4 From models to materials

Lesson 1

Topic	**Structure 2 Models of bonding and structure**
Sub-topic	**Structure 2.4 From models to materials**
Guiding Question	**What role do bonding and structure have in the design of materials?**
Understandings	2.4.1 – The bonding triangle 2.4.2 – Application of the bonding triangle
Level	SL and HL
Duration	1.5 hours
Content statements	• Bonding is best described as a continuum between the ionic, covalent and metallic models, and can be represented by a bonding triangle. • The position of a compound in the bonding triangle is determined by the relative contributions of the three bonding types to the overall bond.
Learning outcomes	• Use bonding models to explain the properties of a material. • Determine the position of a compound in the bonding triangle from electronegativity data. • Predict the properties of a compound based on its position in the bonding triangle.
Prior knowledge	The concept of the bonding triangle will make more sense if the discrete models of ionic (Structure 2.1), covalent (Structure 2.2) and metallic (Structure 2.3) bonding are first understood. An understanding of electronegativity (Structure 3.1) is also essential here, and it is recommended that the electronegativity table from Section 9 of the data booklet is available for reference throughout this lesson.
Lesson context and opening question	Consider examples of elements or compounds that are not completely described by one of the three bonding models. For example, how does the polar nature of water make it behave differently from non-polar covalent molecules? In what ways do the properties of metalloids such as silicon, Si, differ from those of metals? Leads to a discussion of ‘blurred boundaries’ between bonding types.
Key concepts	• Electronegativity values → position of a material in the bonding triangle → prediction and explanation of many properties. • The position of an element or compound in the bonding triangle is determined by the magnitude and difference of the electronegativities of the constituent elements.

Plan for how students will acquire knowledge, understanding and skills	• Read pages 266–268 which cover the concept of a bonding continuum represented by the bonding triangle. • Refer to the bonding triangle provided in Section 17 of the data booklet. • Consider the Linking Question on page 267 which explores an example of the link between trends in properties and trends in bonding. • Consider the Linking Question and answer on page 268. The TOK feature box on page 266 is also relevant here. • Read pages 269–270 which cover the application of electronegativity values to the bonding triangle. • Study the Worked example on page 269. Follow the steps in determining the position of a substance in the bonding triangle. • Consider the Linking Question on page 270, alongside the Global context feature box and photographs on this page. • Attempt Exercise questions 1–3 on page 270.
Activities	Lab skills PDFs: • Structure 2.4 Properties of ionic and covalent compounds • Structure 2.4 Cement and mortar
Links to IB concepts (e.g. NOS, TOK)	The TOK question on page 266 and NOS feature box on 267 can be revisited at the end of the lesson.
Key questions to check for understanding	Practice questions 2, 4, 5, 8 and 10 on pages 286–287.
Additional resources for support/extension	Think of other examples of composites that are widely used, and how their properties can be explained through their bonding.
Guiding Question re-visited	**What role do bonding and structure have in the design of materials?** • Bonding in materials is best described as a continuum rather than as discrete types, and can be represented as a triangle of bonding. • The position of an element or compound in the bonding triangle is determined from electronegativity values. • From the position of a substance in the bonding triangle, we can deduce its bonding and predict its properties.

Lesson 2

Topic	**Structure 2 Models of bonding and structure**
Sub-topic	**Structure 2.4 From models to materials**
Guiding Question	**What role do bonding and structure have in the design of materials?**
Understanding	2.4.3 – Alloys
Level	SL and HL
Duration	1 hour
Content statement	• Alloys are mixtures of a metal and other metals or non-metals. They have enhanced properties.
Learning outcome	• Explain the properties of alloys in terms of non-directional bonding.
Prior knowledge	This will be better understood if students already have a sound grasp of metallic bonding as a lattice of cations with delocalized electrons (Structure 2.3), and the definition of mixtures as containing more than one substance in no fixed ratio (Structure 1.1.1).
Lesson context and opening question	An opening question asking to identify and name metallic objects in the immediate environment should reveal that alloys are more commonly used than pure metals (e.g. steel, brass, solder, sterling silver). Why is this? Leads to a discussion of enhanced properties.
Key concept	• Alloys are homogeneous mixtures containing at least one metal, and held together by metallic bonding.
Plan for how students will acquire knowledge, understanding and skills	• Provide examples of metals and alloys for students to see and feel, to help identify physical properties. • Demonstrate a homogeneous mixture, for example adding ethanol to water, to illustrate its properties. • Read pages 271–273 which cover how alloys are produced by mixing metals in the liquid state, and their structure as a modification of the metallic model of bonding. • Consider the Linking Question on page 273. • Attempt Exercise questions 4–7 on page 273.
Activities	Use the table of alloys on page 272 to spark observation and discussion of common alloys, and what properties make them fit for purpose. Note there should *not* be any emphasis on learning the component metals of specific alloys.
Links to IB concepts (e.g. NOS, TOK)	The steel industry (Global context feature box and photo page 273) is an excellent topic to consider the impact of chemical industries from the environmental, economic and sustainability perspectives.

Key questions to check for understanding	Practice questions 1 and 7 on pages 285–286.
Additional resources for support/extension	Discuss the Challenge yourself question on page 273.
Guiding Question re-visited	Alloys are an excellent example of how understanding the models of bonding and structure has led to the design of materials for specific functions. **What role do bonding and structure have in the design of materials?** • Alloys are homogeneous mixtures of metals with enhanced properties. • Metals are able to form alloys because of the non-directional nature of metallic bonding.

Lesson 3

Topic	**Structure 2 Models of bonding and structure**
Sub-topic	**Structure 2.4 From models to materials**
Guiding Question	**What role do bonding and structure have in the design of materials?**
Understanding	2.4.4 – Polymers
Level	SL and HL
Duration	Less than 1 hour
Content statement	• Polymers are large molecules, or macromolecules, made from repeating subunits called monomers.
Learning outcome	• Describe the common properties of plastics in terms of their structure.
Prior knowledge	This will be better understood if students already have a good knowledge of covalent bonding (Structure 2.2), and some introductory understanding of organic chemistry, specifically carbon's ability to form single and multiple bonds with itself and strong bonds with other elements (Structure 3.2). Some familiarity with IUPAC nomenclature will also be useful here.
Lesson context and opening question	An opening demonstration of linking paper clips (see photograph on page 274) can lead to the question of why this is possible. For example, why could tennis balls not join together in this way? This leads to a discussion of what properties monomers must possess that enable them to form polymers.
Key concept	• Polymers form when monomers link together by covalent bonds, forming large molecules with repeating units.

Plan for how students will acquire knowledge, understanding and skills	• Read page 274 which covers the concept of monomers linking together by covalent bonds to form polymers, shown using repeating units. • Read pages 274–276 which describe natural and synthetic polymers, including the benefits and burdens of plastics. • Demonstrate and describe the widespread occurrence and diversity of polymers in nature, for example by showing egg white and hair as proteins, starch from rice and cellulose in paper as carbohydrates. Nucleic acids are harder to visualise, but the names DNA and RNA will be familiar. • Demonstrate and describe a wide range of synthetic polymers, for example nylon, polystyrene, polythene, PVC, Kevlar etc. • Use the immediate environment of the classroom to identify the widespread use of plastics and the properties that make them useful for diverse functions. • Discuss some of the problems resulting from large-scale global production of plastics, and why their disposal is difficult. • Consider the Linking Question and answer on page 276.
Activities	Lab skills PDFs: • Structure 2.4 Properties of polymers • Structure 2.4 Making polymers
Links to IB concepts (e.g. NOS, TOK)	The plastics industry raises many questions of global concern, as noted in the Global context feature box on page 275 and the NOS feature box on page 276. This can lead to debate and possible CAS projects.
Guiding Question re-visited	**What role do bonding and structure have in the design of materials?** • Polymers are macromolecules composed of subunits called monomers held together by covalent bonds. • Plastics are polymers with properties that give them widespread uses in almost all aspects of society. • The distinct properties of plastics also cause them to accumulate in the environment without being broken down. • Use of biodegradable plastics and recycling programs are important steps to improve the processing of plastic waste, but the urgent need is to reduce the global production of plastic.

Lesson 4

Topic	**Structure 2 Models of bonding and structure**
Sub-topic	**Structure 2.4 From models to materials**
Guiding Question	**What role do bonding and structure have in the design of materials?**
Understanding	2.4.5 – Addition polymers
Level	SL and HL
Duration	Less than 1 hour
Content statement	• Addition polymers form by the breaking of a double bond in each monomer.
Learning outcome	• Represent the repeating unit of an addition polymer from given monomer structures.
Prior knowledge	This will likely be taught immediately after, or alongside, Structure 2.4.3. Knowledge of carbon-carbon double bonds in organic chemistry, and the tendency of alkenes to undergo addition reactions (Reactivity 3.4.5) is essential background here.
Lesson context and opening question	What must happen for alkenes to react together? Students can act out the cartoon diagram on page 277, starting with arms folded (double bond), then uncrossing the arms (bond breakage) to link with a neighbour (bond formation). Does anything have to be lost for this to occur?
Key concept	• An addition polymer is formed when the double bonds of monomer molecules break and make new covalent bonds with neighbouring molecules to form a chain. No other product is formed.
Plan for how students will acquire knowledge, understanding and skills	• Consider the Linking Question on page 277, which is addressed in the opening question above. • Read pages 277–278 which show the repeating units of addition polymers from different monomers. • Study the Worked example on page 278 to see the steps in determining the repeating unit. Note how this uses the approach suggested in the Hint on page 277. • Use this same approach to answer the Challenge yourself question on page 279. • Consider the Linking Question and answer on page 278. • <HL ONLY> Compare the atom economy of addition and condensation polymers. • Attempt Exercise questions 8–11 on page 279.
Activities	Identify common plastics which are addition polymers by considering familiar names such as polythene, polystyrene, polypropylene - and noting the 'ene' suffix. Labels on clothing may yield additional names of fabrics based on addition polymers.

	Video: Animation showing the formation of a long chain of the plastic polythene from molecules of ethene. https://www.sciencephoto.com/media/483210/view
Links to IB concepts (e.g. NOS, TOK)	The vast impact of the manufacture and disposal of addition polymers on everyday life, health and the environment lends itself to discussion and debate. See the Global context feature box on page 276 and the information about microplastics on page 278. There is potential here for individual investigations and CAS projects.
Key questions to check for understanding	Practice questions 3, 6 and 9 on pages 286–287.
Additional resources for support/extension	
Guiding Question re-visited	**What role do bonding and structure have in the design of materials?** • Addition polymers form from monomers that possess a double bond which can break to create new bonding positions for the attachment of neighbouring monomers. • Addition polymerization reactions do not yield a by-product.

Lesson 5

Topic	**Structure 2 Models of bonding and structure**
Sub-topic	**Structure 2.4 From models to materials**
Guiding Question	**What role do bonding and structure have in the design of materials?**
Understanding	2.4.6 – Condensation polymers
Level	HL ONLY
Duration	1 hour
Content statement	• Condensation polymers form by the reaction between functional groups in each monomer with the release of a small molecule.
Learning outcome	• Represent the repeating unit of polyamides and polyesters from given monomer structures.
Prior knowledge	This might be taught immediately after Structure 2.4.3 and Structure 2.4.4, or as an extension to the chemistry of functional groups in Structure 3.2.4. Students who also study biology may be aware of condensation and hydrolysis reactions from anabolic and catabolic processes respectively.

Lesson context and opening question	A possible extension of the cartoon to illustrate addition polymerization on page 277 would be for students to stand alongside each other, all wearing gloves. In order to link hands, the gloves must be removed. The discarded gloves form a pair at each link, representing the small molecule that is lost in the condensation reaction. Note for a chain to form, each person (monomer) must have two gloved hands (functional groups).
Key concept	• Condensation polymers form between monomers which each have two functional groups to react. A small molecule is released for each covalent bond that forms between the monomers.
Plan for how students will acquire knowledge, understanding and skills	• Study or review the structure of carboxylic acid, alcohol, amine, ester and amide functional groups. • Read pages 280–281 which cover condensation reactions and the formation of ester linkages. • Note the suggestion of drawing the monomer structures to focus on the two functional groups and consider the rest of the molecule as an unreactive 'box'. Use this format to practise drawing the reaction that produces an ester linkage. • Study the Worked Example on page 282 which shows how to deduce the reactants from a given repeating unit. This is an example of a hydrolysis reaction described on pages 283–284. • Attempt Exercise questions 13 and 14a on page 284. • Read pages 282–283 which cover the formation of amide linkages. • Study the formation of nylon, and of Kevlar in the Worked example, on page 283. Note that the amide link that forms between carboxylic acid and amine groups is the same in these different examples. • Attempt Exercise questions 12, 14b and 15 on page 284. • Deduce the structure of monomers by considering hydrolysis reactions of condensation polymers. • Discuss the wide-spread occurrence of condensation polymers, both natural and synthetic and their diverse properties and functions. • Consider the Linking Question on page 283, which summarises much of this lesson.
Activities	Identify common plastics which are condensation polymers by considering familiar names such as polyesters and polyamides. **Video:** Making nylon. The two monomers are mixed without stirring and react at the interface to produce nylon threads, which are drawn out of the solution. https://www.sciencephoto.com/media/578357/view

Links to IB concepts (e.g. NOS, TOK)	Further discussion on the impact of polymers on everyday life can focus on condensation polymers. Understanding that natural polymers decompose by hydrolysis reactions catalyzed by enzymes leads to a discussion about the features of biodegradable and compostable plastics, as described on page 276. Further reference to recycling, as described on page 281, is also relevant here.
Key questions to check for understanding	Practice questions 11 and 12 on page 287.
Additional resources for support/extension	• Consider which monomers would produce small molecule by-products other than H_2O. • Compare the atom economy of addition and condensation reactions.
Guiding Question re-visited	**What role do bonding and structure have in the design of materials?** • Condensation polymers form from monomers with two functional groups which can react with the functional groups on neighbouring monomers. • Condensation polymerization reactions release a small molecule for each covalent bond formed. • Condensation polymers break down by hydrolysis reactions in which a small molecule is added for each bond broken in the polymer.